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Aircraft Airframe Cost Estimating Relationships: Attack Aircraft

R. W. Hess, H. P. Romanoff

December 1987

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This Note is part of a series of Notes that derive a set of equations suitable for estimating the acquisition costs of various types of aircraft airframes in the absence of detailed design and manufacturing information. A single set of equations was selected as being the most representative and applicable to the widest range of estimating situations. For attack aircraft, no single acceptable estimating relationship could be identified because sample sizes were small and not homogeneous. Estimates for these aircraft should be developed by analogy or by using the equation set developed for all mission types.

A RAND NOTE

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Aircraft Airframe Cost Estimating Relationships: Attack Aircraft

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Prepared for
The United States Air Force

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PREFACE

This Note describes an attempt to develop a set of equations suitable for estimating the acquisition costs of attack aircraft airframes in the absence of detailed design and manufacturing information. In broad form, the research represents an extension of the results published in J. P. Large et al., *Parametric Equations for Estimating Aircraft Airframe Costs*, The RAND Corporation, R-1693-1-PA&E, February 1976, and used in the RAND aircraft cost model, DAPCA: H. E. Boren, Jr., *A Computer Model for Estimating Development and Procurement Costs of Aircraft (DAPCA-III)*, The RAND Corporation, R-1854-PR, March 1976.

The present effort was undertaken in the context of a larger overall study whose objectives included: (a) an analysis of the utility of dividing the full estimating sample into subsamples representing major differences in aircraft type (attack, fighter, and bomber/transport; and (b) an examination of the explanatory power of variables describing program structure and airframe construction techniques. Additionally, for the fighter subsample only, the study investigated the possible benefits of incorporating an objective technology measure into the equations. A detailed description of the overall study, including the research approach, evaluation criteria, and database may be found in R. W. Hess and H. P. Romanoff, *Aircraft Airframe Cost Estimating Relationships: Study Approach and Conclusions*, The RAND Corporation, R-3255-AF, December 1987.

To address the issue of sample homogeneity, each of the subsamples, as well as the full sample, had to be investigated in detail with the ultimate goal of developing a representative set of cost estimating relationships (CERs) for each. The purpose of this Note is, therefore, to document the analysis of the attack aircraft subsample. Study results concerning the full estimating sample as well as the other subsamples are available in a series of companion Notes:

Aircraft Airframe Cost Estimating Relationships: All Mission Types, N-2283/1-AF, December 1987.

Aircraft Airframe Cost Estimating Relationships: Fighters, N-2283/2-AF, December 1987.

Aircraft Airframe Cost Estimating Relationships: Bombers and Transports, N-2283/3-AF, December 1987.

This research was undertaken as part of the Project AIR FORCE study entitled "Cost Analysis Methods for Air Force Systems," which has been superseded by "Air Force Resource and Financial Management Issues for the 1980s" in the Resource Management Program.

While this report was in preparation, Lieutenant Colonel H. P. Romanoff, USAF, was on duty in the System Sciences Department of The RAND Corporation. At present, he is with the Directorate of Advanced Programs in the Office of the Assistant Secretary of the Air Force for Acquisition.

SUMMARY

This Note documents an attempt to derive a set of equations suitable for estimating the acquisition costs of attack aircraft airframes. The estimating sample consists of seven attack aircraft with first flight dates ranging from 1953 to 1974. The aircraft technical data were for the most part obtained from either original engineering documents such as manufacturer's performance substantiation reports or from official Air Force and Navy documents. The cost data were obtained from the airframe manufacturers either directly from their records or indirectly through standard Department of Defense reports such as the Contractor Cost Data Reporting System.

The key result of this effort is that we were unable to identify a single acceptable estimating relationship for any of the individual cost elements or for the total program cost element. This discouraging result is not too surprising, however, since the attack aircraft sample is very small and not especially homogeneous. Estimates for proposed attack aircraft should be developed on the basis of analogy (using the data provided in this Note) or by using the equation set developed for all mission types (N-2283/1-AF).

CONTENTS

FIGURES

TABLES

MNEMONICS

AUW	Airframe unit weight (lb)
AVAUW	Ratio of avionics weight to airframe unit weight
CA	Cumulative average
DS	Development support cost (thousands of 1977 dollars)
$ENGR_{100}$	Cumulative engineering hours for 100 aircraft (thousands)
EW	Empty weight (lb)
EWAUW	Ratio of empty weight less airframe unit weight to airframe unit weight
FT	Flight test cost (thousands of 1977 dollars)
$LABR_{100}$	Cumulative manufacturing labor hours for 100 aircraft (thousands)
$MATL_{100}$	Cumulative manufacturing material costs for 100 aircraft (thousands of 1977 dollars)
$PROG_{100}$	Cumulative total program cost for 100 aircraft (thousands of 1977 dollars)
Q	Quantity
QC_{100}	Cumulative quality control hours for 100 aircraft (thousands)
SPCLS	Speed class (1 $<$ M .95; 2 = M .95 to 1.94; 3 = M 1.95 to M 2.5)
TESTAC	Number of flight test aircraft
$TOOL_{100}$	Cumulative tooling hours for 100 aircraft (thousands)
WTAREA	Wetted area (sq ft)

EVALUATION CRITERIA NOTATION

Notation	Explanation
EQ SIG: F-TEST	Equation as a whole is not significant at 5 percent level (based on F-statistic)
EXP MAG: variable mnemonic	Question exists regarding magnitude of variable exponent (reasonableness)
EXP SIGN: variable mnemonic	Sign of variable exponent does not agree with a priori notions
F	F-statistic
IO: aircraft identification	Based on "Cook's Distance," aircraft is indicated to be influential observation
LDIFF: variable mnemonic	Limited differentiation in dummy variable; coefficient determined by single observation or portion of dummy variable range not included in a subsample
MCOL: r (variable) > .7, .8, or .9	Indicates degree of intercorrelation of specified variable with other equation variables (only provided when threshold of .7 is exceeded)
N	Number of observations
R^2	Coefficient of determination
RP: CUR: OVER/UNDER	Residual pattern indicates that the most recently developed aircraft in the sample are over or underestimated
RP: DIST	Residual pattern indicates that the error is not normally distributed with zero mean and constant variance
SEE	Standard error of estimate
VAR SIG: variable mnemonic	Variable is not significant at the 5 percent level (t-statistic)[1]

[1]Variable significance is provided in parentheses beneath each variable.

I. INTRODUCTION

Parametric models for estimating aircraft airframe acquisition costs have been used extensively in advanced planning studies and contractor proposal validation. These models are designed to be used when little is known about an aircraft design or when a readily applied validity and consistency check of detailed cost estimates[1] is necessary. They require inputs that: (a) will provide results that are relatively accurate, (b) are logically related to cost, and (c) can easily be projected prior to actual design and development information. The intent is to generate estimates that include the cost of program delays, engineering changes, data requirements, and phenomena of all kinds that occur in a normal aircraft program.

Since 1966, RAND has developed three parametric airframe cost models.[2] These models have been characterized by: (a) easily obtainable size and performance inputs (weight and speed), (b) the estimation of costs at the total airframe level, and (c) the utilization of heterogeneous aircraft samples. They have normally been updated when a sufficient number of additional aircraft data points has become available to suggest possible changes in the equations. Such is the case with the present effort: the A-10, F-15, F-16, F-18, F-101, and S-3 aircraft have been added to the full estimating sample.[3]

In addition to the expansion of the database, we also examined: (a) the utility of dividing the estimating sample into subsamples representing major differences in aircraft type (attack, fighter, bomber/transport), (b) the explanatory power of variables describing

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[1]Examples of this latter application include the Independent Cost Analysis (ICA) prepared as part of the Defense Systems Acquisition Review Council (DSARC) process, and government analyses of contractor cost proposals during source selections.

[2]See Refs. 1, 2, and 3.

[3]Additionally, the F-86, F-89, and F3D, which were dropped from the previous estimating sample, were reintroduced.

program structure and airframe construction techniques, and (c) the possible benefits of incorporating an objective technology measure into the fighter sample equations. To address the issue of sample homogeneity, each of the subsamples, as well as the full sample, had to be investigated in detail with the ultimate goal of developing representative sets[4] of cost-estimating relationships (CERs) for each. This Note documents the analysis of the attack aircraft subsample.

Section II briefly describes the database and statistical analysis methods. Section III gives some general indication, based on initial observations, of what can be expected in subsequent sections. Sections IV through XI provide, by cost element, data plots and each of the estimating relationships that meets our initial screening criterion with respect to variable significance. Section XII summarizes the main findings of the study. The appendix contains correlation matrixes.

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[4]A set encompasses the following cost elements: engineering, tooling, manufacturing labor, manufacturing material, development support, flight test, and quality control.

II. DATABASE AND ANALYTICAL APPROACH

A detailed description of the research approach, evaluation criteria, and database for this study may be found in R-3255-AF. For this Note to have a degree of self-sufficiency, however, a synopsis is provided here of the database and analytical approach.

ESTIMATING SAMPLE

The full attack aircraft estimating sample consists of the following seven "new design" aircraft:[1]

Model	First Flight Date[2]
A-3	1953
A-4	1954
A-5	1958
A-6	1960
A-7	1965
A-10	1974
S-3	1972

Some question may be raised concerning the inclusion of the S-3 in the attack subsample. Such characteristics as weight, speed, climb rate, and ultimate load factor place it within the range of the mission code 'A' aircraft. Furthermore, its relatively steep dive angle gives it the capability to be used in an attack role (for torpedos and depth bombs). Because of these features, its inclusion in the attack sample was felt appropriate.

[1]The classification of an aircraft as new or derivative is not an entirely objective procedure. For example, although the A-7 evolved from the F-8, the A-7 is classified as a new design in the database. Compared with the F-8, the A-7 is shorter in length (47 ft vs. 54 ft), has slightly reduced wing sweepback, outboard ailerons, a non-afterburning turbofan engine (maximum speed of Mach 0.8 vs. Mach 1.7), and a fixed incidence wing. [Ref. 4, pp. 163-164]

[2]The first flight dates presented in this Note are intended to reflect the first flight date of the version of the aircraft that was most representative of the aircraft which was to become operational. Put another way, these dates are intended to reflect the first flight

DEPENDENT VARIABLES

Costs have been dealt with at both the total program level[3] and at the major cost element level (engineering, tooling, manufacturing labor, manufacturing material, development support, flight test, and quality control).[4] The relative importance of the various cost elements is shown in Table 1 for four alternative production quantities. Other things being equal, the accuracy of the estimating relationship for manufacturing labor is of greatest concern because of the relatively large share of program cost represented by that cost element.

Table 1

PERCENTAGE BREAKDOWN OF ATTACK AIRCRAFT
AIRFRAME PROGRAM COSTS

(7 aircraft average costs)

	Quantity			
Cost Element	25	50	100	200
Engineering	30	26	22	18
Tooling	15	15	13	12
Manufacturing labor	25	30	36	40
Manufacturing material	8	11	14	18
Development support	9	7	5	4
Flight test	10	7	6	4
Quality control	3	4	4	4
	100	100	100	100

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date of the developmental aircraft and not earlier experimental or prototype aircraft.

[3]Total program costs are "normalized" values and not the actual reported dollar amounts. They are normalized in the sense that the dollar amounts for engineering, tooling, manufacturing labor, and quality control have been determined by applying fully burdened, industry-average labor rates to the hours reported for each category.

[4]Cost element definitions are provided in App. A of R-3255-AF.

Engineering, tooling, manufacturing labor, and quality control are estimated in terms of manhours rather than dollars for two reasons: (a) it avoids the need to make adjustments for annual price changes, and (b) it permits comparison of real differences in labor requirements.[5] Manufacturing material, development support, and flight test do not lend themselves to this approach and were therefore estimated in terms of dollars (in this case, constant 1977 dollars).

POTENTIAL EXPLANATORY VARIABLES

To be included among the characteristics that were considered for the CERs, the following requirements must have been fulfilled:

1. The variable had to be logically related to cost: that is, a rationale had to be constructed that would explain why cost should be influenced by the variable.
2. The variable had to be one which was "readily available" in the early stages of aircraft conceptualization.
3. The variable had to have an *available* historical record.

During the formulation stage of this study, 20 aircraft characteristics were identified as potential explanatory variables for the attack aircraft sample CERs. Values for these characteristics, which are grouped into four general categories--size, performance, construction, and program--are provided in Table 2. Based on this table, the following observations are made:

1. Based on airframe unit weight, the A-4 is less than half as big as the next smallest aircraft in the sample.
2. With regard to speed, all aircraft in the sample are subsonic with the exception of the A-5, which is a Mach 2 aircraft. Similarly, the A-5 climb rate is over twice that of the next fastest climbing aircraft in the sample.

[5]The major limitation of the manhour approach is that it does not account for differences in overhead rates. Consequently, differences in such things as capital/labor ratios cannot be addressed.

Table 2

ATTACK AIRCRAFT CHARACTERISTICS

Characteristic	A-3	A-4	A-5	A-6	A-7	A-10	S-3	Mean	Standard Deviation
Size									
Airframe unit weight (AUW)	23,931	5,072	23,499	17,150	11,621	14,842	18,536	16,379	6,656
Empty weight (EW)	35,999	9,146	32,714	25,298	15,497	19,856	26,581	23,584	9,461
Wetted area	3,899	1,144	2,950	2,100	1,690	2,463	2,607	2,408	891
Technical/performance									
Maximum speed	546	565	1,147	561	595	389	429	605	251
Speed class (a)	1	1	3	1	1	1	1	--	--
Climb rate	5,050	8,400	27,900	10,000	8,580	5,100	5,000	10,004	8,150
Useful load fraction	.485	.594	.439	.583	.578	.559	.494	.533	.060
Construction									
Design ultimate load factor	5.00	10.50	11.00	9.75	10.50	4.93	5.25	8.13	2.90
Carrier capability designator (b)	2	2	2	2	2	1	2	--	--
Engine location designator (c)	2	1	1	1	1	2	2	--	--
Wing type (d)	2	2	2	2	2	1	2	--	--
Ratio of wing area to wetted area	.200	.227	.237	.251	.222	.205	.230	.225	.018
Ratio of (EW-AUW)/AUW	.50	.80	.39	.48	.33	.34	.44	.47	.16
Ratio of avionics weight to AUW	.085	.084	.110	.170	.059	.041	.220	.110	.064
Number of black boxes	8	6	13	23	19	14	33	17	9
Program									
Number of test aircraft	5	9	11	8	7	8	8	8	2
Maximum tooling capability	8	40	6	8	24	15	5	15	13
New engine designator (b)	1	1	1	2	1	1	2	--	--
Contractor experience designator (e)	2	1	2	2	1	2	2	--	--
Program type designator (f)	2	2	1	1	1	2	1	--	--

(a)Speed class: 1 = less than Mach .95; 2 = Mach .95 to Mach 1.94; 3 = Mach 1.95 to Mach 2.5.
(b)No = 1; Yes = 2.
(c)Engine location: 1 = embedded in fuselage; 2 = in nacelles.
(d)Wing type: 1 = straight; 2 = swept; 3 = delta; 4 = variable sweep.
(e)Yes = 1; No = 2.
(f)Program type: concurrent = 1; prototype = 2.

3. The electronics emphasis of the S-3 is reflected in its black box count and its ratio of avionics weight to airframe unit weight, both of which fall approximately two standard deviations above the mean.
4. With the exception of the A-10, all aircraft in the sample are carrier capable. Similarly, the A-10 is the only aircraft in the sample that does not have swept wings.
5. The maximum tooling capability of the A-4 program is approximately 70 percent greater than that of the next largest program.

A priori notions regarding the effect an increase in the value of an explanatory variable might have on each of the cost elements is indicated in Table 3. A plus indicates a positive effect; a minus a negative effect. An effect which was thought to be negligible is indicated by a blank, while an uncertain effect is indicated by a question mark.

APPROACH

Potential explanatory variables have been divided into four general categories--size, performance, construction, and program (see Table 3). As discussed in Sec. IV of R-3255-AF, the "ideal" airframe cost estimating relationship would incorporate one explanatory variable from each category. Thus, there would be four independent variables per estimating relationship. For the full estimating sample, which has 34 observations, the possible incorporation of four independent variables presents no difficulties since there would still be 29 degrees of freedom left with which to estimate the error term. Unfortunately, the attack aircraft subsample has only seven observations and the incorporation of four explanatory variables would leave only two degrees of freedom with which to estimate the error term. Consequently, the number of explanatory variables considered per equation for the attack aircraft sample was tentatively limited to two.[6]

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[6]We do not mean to suggest that this limit is an "absolute" maximum for it is not (theoretically, one could use five explanatory variables

Table 3

A PRIORI NOTIONS REGARDING EFFECT OF INCREASE IN EXPLANATORY VARIABLE ON COST ELFMENT

Explanatory Variable	Engr.	Tooling	Mfg. Labor	Mfg. Material	Dev. Support	Flight Test	Quality Control	Total Program
Size								
Airframe unit weight (AUW)	+	+	+	+	+	+	+	+
Empty weight (EW)	+	+	+	+	+	+	+	+
Wetted area	+	+	+	+	+	+	+	+
Technical/performance								
Maximum speed	+	+	+	+	+	+	+	+
Speed class (a)	+	+	+	+	+	+	+	+
Climb rate	+	+	+	+	+	+	+	+
Useful load fraction	+	+	+	+				+
Construction								
Design ultimate load factor	+		+	+	+			+
Carrier capability designator (b)	+		+	+	+	+		+
Engine location designator (c)	-	?	-	+				?
Wing type (d)	+	+	+		+	+		+
Ratio of wing area to wetted area		-	-					-
Ratio of (EW-AUW)/AUW	+		+	+	+	+	+	+
Ratio of avionics weight to AUW	+		+	+	+	+	+	+
Number of black boxes	+		+	+	+	+	+	+
Program								
Number of test aircraft						+		
Maximum tooling capability		+	-					?
New engine designator (b)	+					+		+
Contractor experience designator (e)	+	+	+	+	+	+	+	+
Program type designator (f)	? (g)	? (g)			? (g)	? (g)		? (g)

(a)Speed class: 1 = less than Mach .95; 2 = Mach .95 to Mach 1.94; 3 = Mach 1.95 to Mach 2.5.
(b)No = 1; Yes = 2.
(c)Engine location: 1 = embedded in fuselage; 2 = in nacelles
(d)Wing type: 1 = straight; 2 = swept; 3 = delta; 4 = variable sweep.
(e)Yes = 1; No = 2.
(f)Program type: concurrent = 1; prototype = 2.
(g)Not known whether total cost (prototype effort plus full-scale development) for prototype program is greater or less than for concurrent program.

With respect to the specific combinations of variable categories examined, it is our understanding that all airframe manufacturers use some measure of size (usually weight) as their basic scaling dimension in developing cost estimates (although other factors frequently do enter in). Consequently, it did not seem unreasonable for a similar assumption to be made on our part--a size variable must appear in all equations (except for flight test, in which case the number of test aircraft is the mandatory variable). With this additional restriction, the specific variable combinations that were examined for the attack aircraft sample are as follows:

Size
Size/performance
Size/construction
Size/program

The first step in developing a representative set of CERs was to identify all potentially useful estimating relationships for each cost element resulting from the variable combinations listed above. For this first step, "potentially useful" included only those estimating relationships in which all equation variables were significant at the 5 percent level. Since the number of variable combinations was relatively small, all possible regressions were run and screened for variable significance. Then, each equation satisfying this initial screening criterion was scrutinized in accordance with a set of evaluation criteria dealing with statistical quality and reasonableness of results (these are described in the next subsection).

The final step was selection of the most suitable estimating relationship for each cost element (i.e., the selection of a representative set). Generally speaking, other things being equal, we tried to select estimating relationships which satisfied the following conditions:

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for an attack aircraft equation and still have one degree of freedom left). It simply reflects our *judgment* regarding an appropriate balance between sample size and the potential number of explanatory variables.

- Each variable significant at the 5 percent level
- Variables taken collectively significant at the 5 percent level
- Produce credible results
- Free of unusual residual patterns

If these conditions were satisfied by more than one equation, then the objective was minimization of the standard error of estimate. Traditionally, cost analysts have *tried* to achieve a standard error of estimate of + or -20 percent or better. For logarithmic models, this is approximately equivalent to 0.18 (+20 percent, -16 percent). On the other hand, if the conditions were not satisfied by any of the equations, then none was recommended.

Multiple regression analysis was the technique used to examine the relationship between cost and the explanatory variables. Because of time restrictions, only one equation form was investigated--logarithmic-linear. The linear model was rejected because its main analytic property--constant returns to scale--does not correspond to real world expectations. Of the two remaining equation forms considered (logarithmic and exponential), the logarithmic model seemed most appropriate for the cost-estimation process since it minimizes relative errors rather than actual errors as in the exponential model.

Cost element categories which are a function of quantity were examined at a quantity of 100. Developing the estimating relationships at a given quantity rather than using quantity as an independent variable in the regression analysis avoids the problem of unequal representation of aircraft (caused by unequal numbers of lots).

EVALUATION CRITERIA

The estimating relationships obtained in this analysis were evaluated on the basis of their statistical quality, intuitive reasonableness, and predictive properties.

Statistical Quality

Variable Significance. Variable significance was an initial screening device to reduce the number of estimating relationships requiring closer scrutiny. Normally, only those equations for which all variables were significant at the 5 percent level (one-sided t-test) were reported in this Note. Occasionally, however, this criterion was relaxed in order that a useful comparison could be provided. When an equation is reported for which not all equation variables are significant at the 5 percent level, it is denoted as follows:

VAR SIG: variable mnemonic

Coefficient of Determination. The coefficient of determination (R^2) was used to indicate the percentage of variation explained by the regression equation.

Standard Error of Estimate. The standard error of estimate (SEE) was used to indicate the degree of variation in the data about the regression equation. It is given in logarithmic form but may be converted into a percentage of the corresponding hour or dollar value by performing the following calculations:

(a) $e^{+SEE}-1$
(b) $e^{-SEE}-1$

For example, a standard error of 0.18 yields standard error percentages of about +20 and -16.

F-Statistic. The F-statistic was used to determine collectively whether the explanatory variables being evaluated affect cost. Those equations for which the probability of the null hypothesis pertaining was greater than 0.05 have been identified as follows:

EQ SIG: F-TEST

Equations so identified were not considered for inclusion in the representative equation set.

Multicollinearity. Estimating relationships containing variable combinations with correlations greater than 0.70 are identified according to the degree of intercorrelation:

MCOL: r(variable mnemonic) > 0.7, 0.8, or 0.9

where the variable identified in parentheses is the equation variable showing the greatest collinearity. Generally speaking, estimating relationships with intercorrelations greater than 0.8 were avoided when selecting the representative equation set.

Residual Plots. Plots of equation residuals were given cursory examinations for unusual patterns. In particular, plots of residuals versus predictions (log/log) were checked to make sure that the error term was normally distributed with zero mean and constant variance. Additionally, plots of residuals versus time (log/linear) were examined to see whether the most recent airframe programs were over- or underestimated. The existence of such patterns resulted in one of the following designations:

RP:DIST (errors not normally distributed)
RP:CUR: OVER or UNDER (most recent aircraft over- or underestimated)

Generally speaking, we *tried* to avoid the use of estimating relationships with patterns in the representative equation set.

Influential Observations. "Cook's Distance" was employed to identify influential observations in the least squares estimates. For this analysis, an influential observation was defined as one which, if deleted from the regression, would move the least squares estimate past the edge of the 10 percent confidence region for the equation coefficients. Such observations are identified as follows:

IO: aircraft identification

When an observation was consistently identified as influential, it was

reassessed in terms of its relevance to the sample in question. If a reasonable and uniform justification for its exclusion could be developed, then the observation was deleted from the sample and the regressions rerun (in actuality, this occurred only once--when the B-58 was deleted from the bomber/transport sample). Otherwise, the influential observation was simply flagged to alert the potential user to the fact that its deletion from the regression sample would result in a significant change in the equation coefficients.

Reasonableness

The development of airframe cost-estimating relationships requires variable coefficients which provide both credible results and conform whenever possible to the normal estimating procedures employed by the airframe industry. Such credibility and conformity are reflected in both the signs of the variable coefficients as well as their magnitudes.

Exponent Sign. Estimating relationships for which the sign of the variable coefficient was not consistent with a priori notions (see Table 4) are identified in the following manner:

EXP SIGN: variable mnemonic

Estimating relationships containing such inconsistencies were not considered for inclusion in the representative equation set.

Exponent Magnitude. Close attention was also paid to the magnitude of variable coefficients. This applied to exponents which were felt to be too small as well as those which were felt to be too large. Estimating relationships containing such variable coefficients are identified as follows:

EXP MAG: variable mnemonic

Although determinations of this kind are largely subjective, there was one application that was relatively objective. Traditionally, size variables have always provided returns to scale in the production-oriented cost elements (tooling, labor, material, and total program

cost). That is, increases in airframe size are accompanied by less than proportionate increases in cost. If the opposite phenomenon is observed, it is generally believed to be the result of not adequately controlling for differences in construction, materials, complexity, or other miscellaneous production factors. Consequently, equations possessing a size-variable coefficient greater than one were always flagged.

When selecting a representative equation set, we generally tried to avoid estimating relationships containing variables with exponents that we felt were either too large or too small (that is, exponents that placed either too much or too little emphasis on the parameter in question). More restrictively, for the production-oriented cost elements, no estimating relationship possessing a size-variable exponent greater than one was considered for a representative equation set.

Predictive Properties

Confidence in the ability of an equation to accurately estimate the acquisition cost of a future aircraft is in large part dependent on how well the acquisition costs of the most recently produced aircraft are estimated. Normally, statistical quality and predictive capability would be viewed as one and the same. Unfortunately, when dealing with airframe costs this is not always the case because our knowledge of what drives airframe costs is limited and because the sample is relatively small in size and not evenly distributed with respect to first flight date (see Fig. 1). Consequently, the estimating relationships were also evaluated on the basis of how well costs for a subset of the most recent aircraft in the database are estimated.

An indication of an equation's predictive capability would usually be obtained by excluding a few of the most recent aircraft from the regression and then seeing how well (in terms of the relative deviation) the resultant equation estimates the excluded aircraft. However, in this case, the small sample size precluded the option. Consequently, the measure of predictive capability used in the analysis was the average of the absolute relative deviations for the A-6, A-10, and S-3. These relative deviations were determined on the basis of the predictive

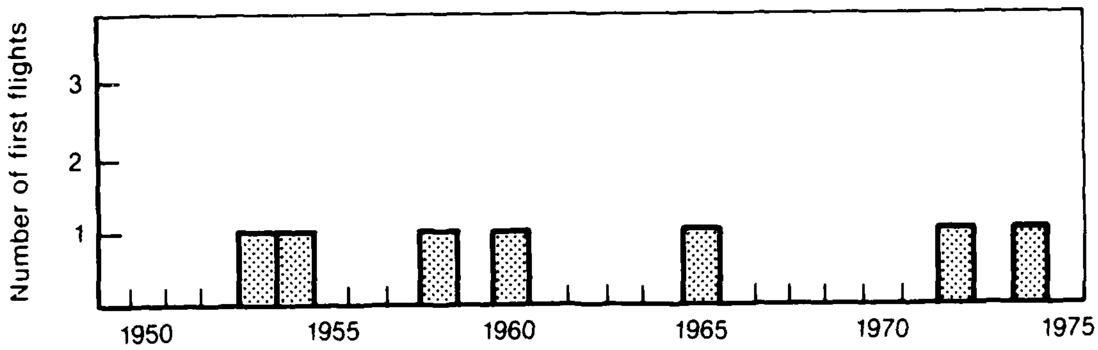

Fig. 1—Number of first flight events as a function of the year of first flight

form of the equation and not the logarithmic form used in the regression.[7]

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[7]If cost is estimated in a log-linear form, such as

$$\ell n \text{ COST} = \beta_0 + \beta_1 \ \ell n \text{ WEIGHT} + \beta_2 \ \ell n \text{ SPEED} + \ell n \ \varepsilon$$

the expected cost is given by

$$\text{COST} = \left(e^{\beta_0} \text{ WEIGHT}^{\beta_1} \text{ SPEED}^{\beta_2} \right) e^{\hat{\sigma}^2/2}$$

where $\hat{\sigma}^2$ is the actual variance of ε in the log-linear equation. Since the actual variance is not known, the standard error of the estimate may be used as an approximation.

III. INITIAL OBSERVATIONS

This section provides an initial overview of the individual cost element analyses which follow.

PERFORMANCE VARIABLES

Only three equations were determined in which both the size and performance variables were significant at the 5 percent level. All three were for the manufacturing material cost element and in each instance the performance variable was the speed class designator. However, confidence in these estimating relationships was diminished by the fact that there are no attack aircraft in speed class 2 and only one in speed class 3. The only significant source of performance variation in the attack aircraft sample is the A-5.

CONSTRUCTION/PROGRAM VARIABLES

The construction/program variables proved to be of little help in improving the quality of the attack aircraft estimating relationships. There were only three instances where such variables were found to be significant at the 5 percent level and, in each case, the overall equations did not produce results that we viewed as credible.

INFLUENTIAL OBSERVATIONS

The A-4, because it is at an extreme of the attack aircraft sample with respect to size, is identified as an influential observation in nearly every equation documented in this Note. This point is easily seen in the representative data plot provided in Fig. 2. However, we did not feel that its small size alone was sufficient reason to exclude it. Furthermore, any attempts to develop simple scaling relationships without the A-4 will result in equations which show extremely strong diseconomies of scale (with respect to size).

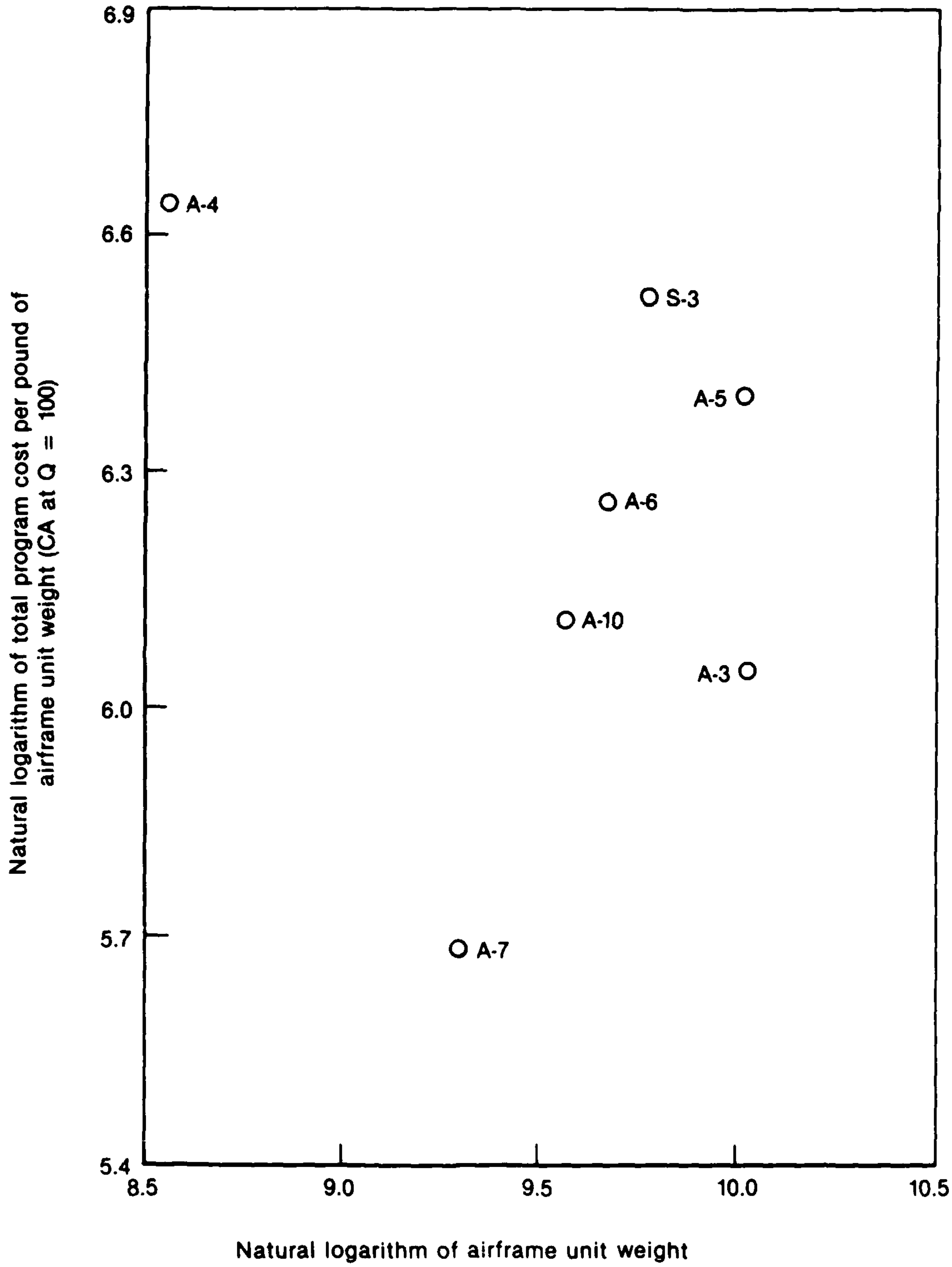

Fig. 2—Typical attack aircraft plot pattern

IV. ENGINEERING

Engineering hours per pound are plotted as a function of airframe unit weight in Fig. 3. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 4. As indicated, we were not able to identify any estimating relationships which satisfied our initial screening criterion regarding variable significance.

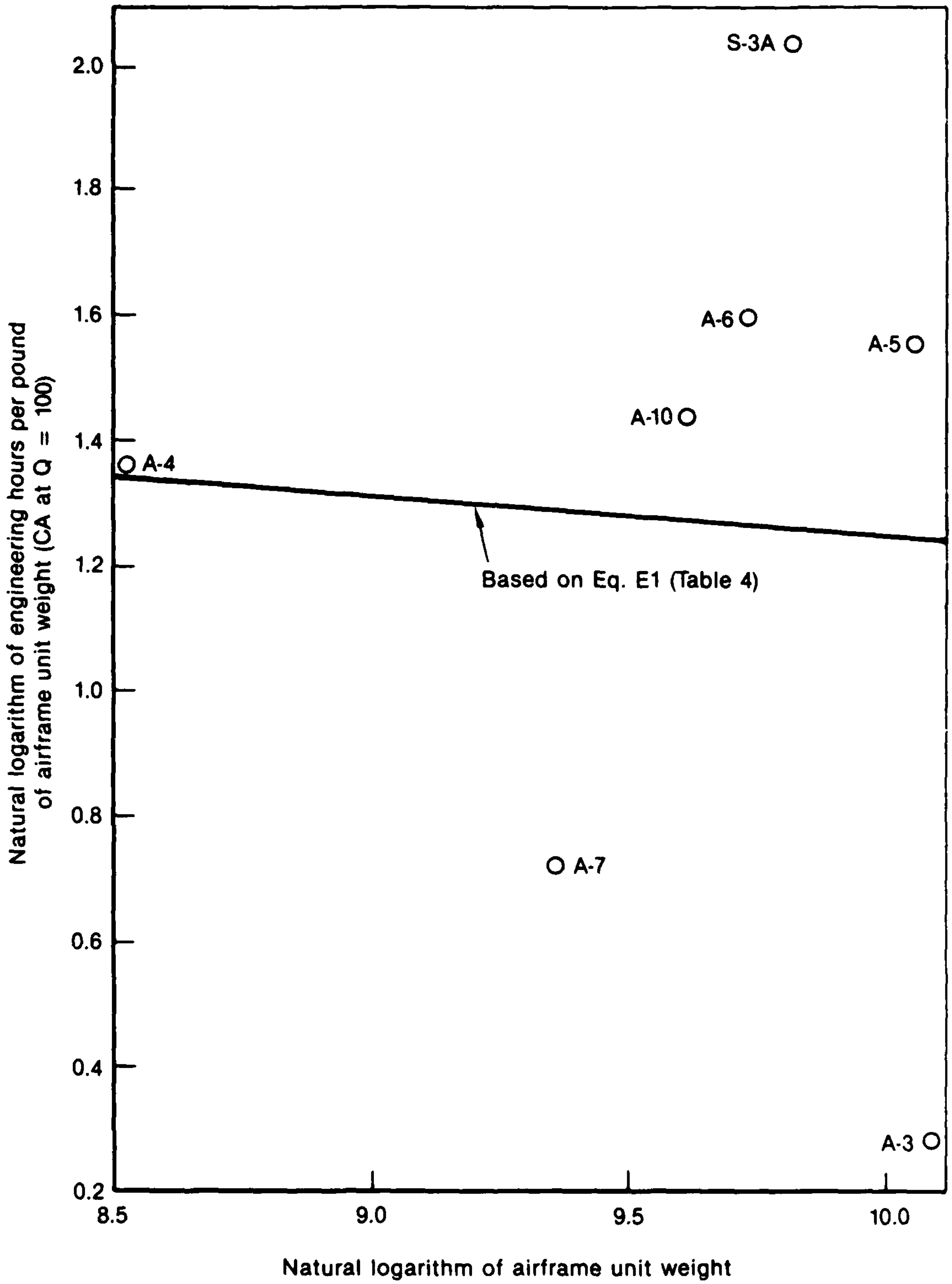

Fig. 3—Engineering hours per pound as a function of airframe unit weight

Table 4

ENGINEERING HOUR ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	SIZE									
E1	$ENGR_{100} = .766\ AUW^{.943}$ (.057)(a)	.42	.65	4	7	+10	-6	+43	20	VAR SIG: AUW EQ SIG: F-TEST IO: A-3, A-7, S-3
E2	$ENGR_{100} = .198\ EW^{1.04}$ (.061)	.41	.66	3	7	+7	+2	+42	17	VAR SIG: EW EQ SIG: F-TEST IO: A-3, S-3
E3	$ENGR_{100} = 3.40\ WTAREA^{.988}$ (.123)	.26	.73	2	7	+22	-23	+43	29	VAR SIG: WTAREA EQ SIG: F-TEST IO: A-3, A-4, S-3
	SIZE/PERFORMANCE									
None										
	SIZE/CONSTRUCTION, PROGRAM									
None										

(a)Variable significance levels are in parentheses.

V. TOOLING

Tooling hours per pound are plotted as a function of airframe unit weight in Fig. 4. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 5. As indicated, we were not able to identify any estimating relationships which satisfied our initial screening criterion regarding variable significance.

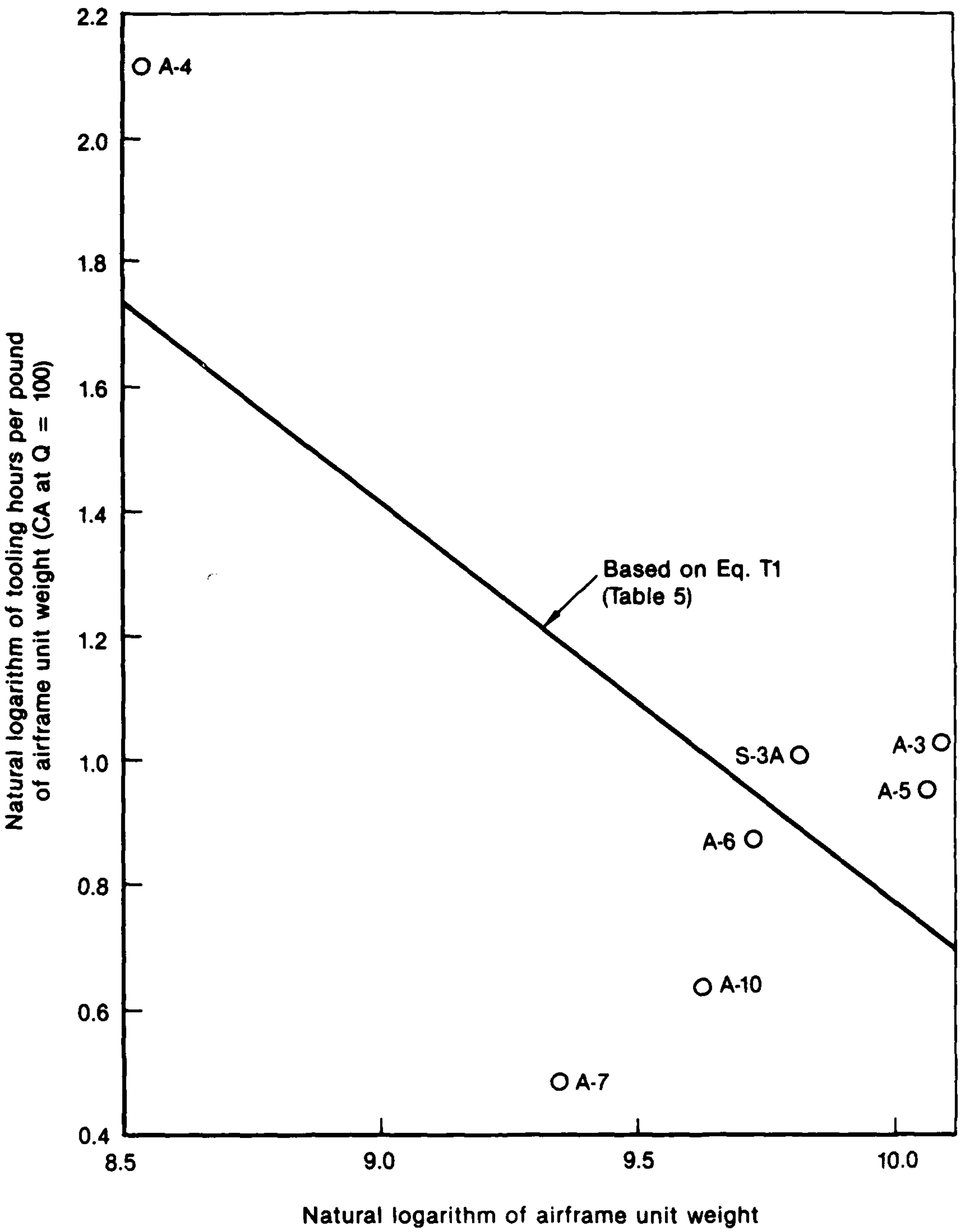

Fig. 4—Tooling hours per pound as a function of airframe unit weight

Table 5

TOOLING HOUR ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	<u>SIZE</u>									
T1	$TOOL_{100} = 137\ \underset{(.166)}{AUW^{.366}}$	.19	.45	1	7	-19	-61	+3	28	VAR SIG: AUW EQ SIG: F-TEST IO: A-3, A-4, A-7
T2	$TOOL_{100} = 20.5\ \underset{(.092)}{EW^{.540}}$	.32	.41	2	7	-20	-51	+2	24	VAR SIG: EW EQ SIG: F-TEST IO: A-3, A-4, A-7
T3	$TOOL_{100} = 37.2\ \underset{(.103)}{WTAREA^{.621}}$	.30	.42	2	7	-6	-67	+4	26	VAR SIG: WTAREA EQ SIG: F-TEST IO: A-3, A-4, A-7 A-10
	<u>SIZE/PERFORMANCE</u>									
None										
	<u>SIZE/CONSTRUCTION, PROGRAM</u>									
None										

VI. MANUFACTURING LABOR

Manufacturing labor hours per pound are plotted as a function of airframe unit weight in Fig. 5. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 6. General observations regarding these equations are as follows:

1. The exponents of the size variables in Eqs. L1 through L5 are all greater than one.
2. None of the size/performance combinations examined satisfied our initial screening criterion with respect to variable significance.
3. The magnitude of the variable EWAUW (ratio of empty weight minus airframe unit weight to airframe unit weight) shows a fair amount of variability depending on the size variable--from 1.20 in L4 to .747 in L5.
4. None of the estimating relationships listed in Table 6 is recommended.

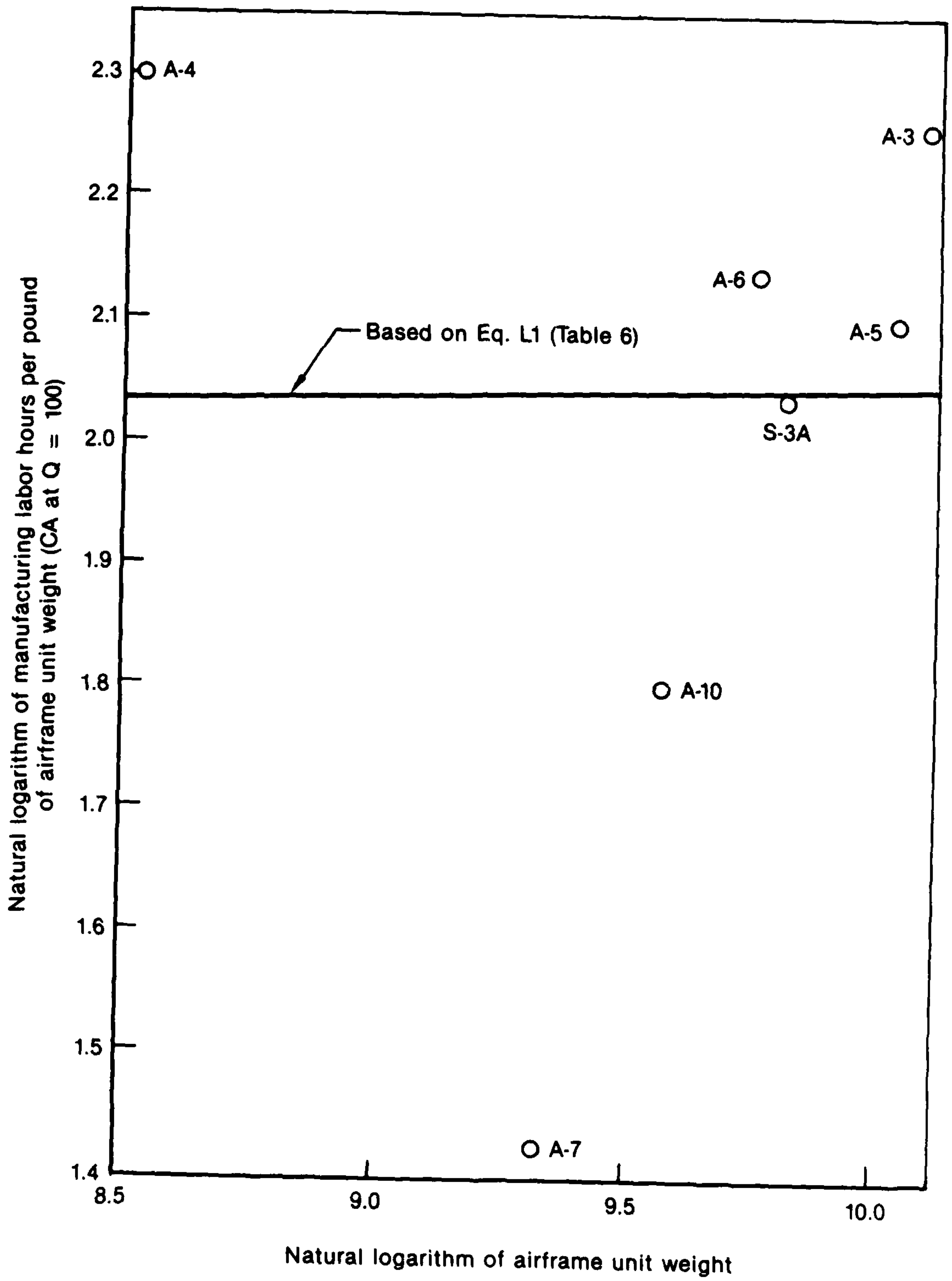

Fig. 5—Manufacturing labor hours per pound as a function of airframe unit weight

Table 6

MANUFACTURING LABOR HOUR ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	SIZE									
L1	$LABR_{100} = .742\ AUW^{1.01}$ (.006)	.75	.34	15	7	+7	-30	-3	13	EXP MAG: AUW IO: A-3, A-4, A-7
L2	$LABR_{100} = .0576\ EW^{1.22}$ (.001)	.87	.24	35	7	+6	-13	-2	7	EXP MAG: EW IO: A-4, A-7
L3	$LABR_{100} = .268\ WTAREA^{1.38}$ (.004)	.78	.32	18	7	+28	-45	+1	25	EXP MAG: WTAREA IO: A-4, A-6, A-7, A-10
	SIZE/PERFORMANCE									
None										
	SIZE/CONSTRUCTION, PROGRAM									
L4	$LABR_{100} = .0454\ AUW^{1.39}\ EWAUW^{1.20}$ (.000) (.001)	.98	.11	103	7	-1	+12	-4	6	EXP MAG: AUW IO: A-3, A-4, A-7, A-10
L5	$LABR_{100} = .0136\ EW^{1.42}\ EWAUW^{.747}$ (.000) (.004)	.98	.10	104	7	0	+12	-3	5	EXP MAG: EW IO: A-3, A-4, A-7, A-10

VII. MANUFACTURING MATERIAL

Manufacturing material cost per pound is plotted as a function of airframe unit weight in Fig. 6. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 7. General observations regarding these equations are as follows:

1. None of the size/construction, program variable combinations examined satisfied our initial screening criterion with respect to variable significance.
2. Confidence in the estimating relationships containing the speed class designator is diminished by the fact that there are no attack aircraft in speed class 2 and only one in speed class 3.
3. The magnitude of the size variable exponent in equation M3 is greater than one. Furthermore, the exponents of the size variables in equations M1 and M2 are determined largely by a single aircraft--the A-4 (that is, deletion of the A-4 would result in equations with size exponents considerably greater than one).
4. None of the estimating relationships listed in Table 7 is recommended.

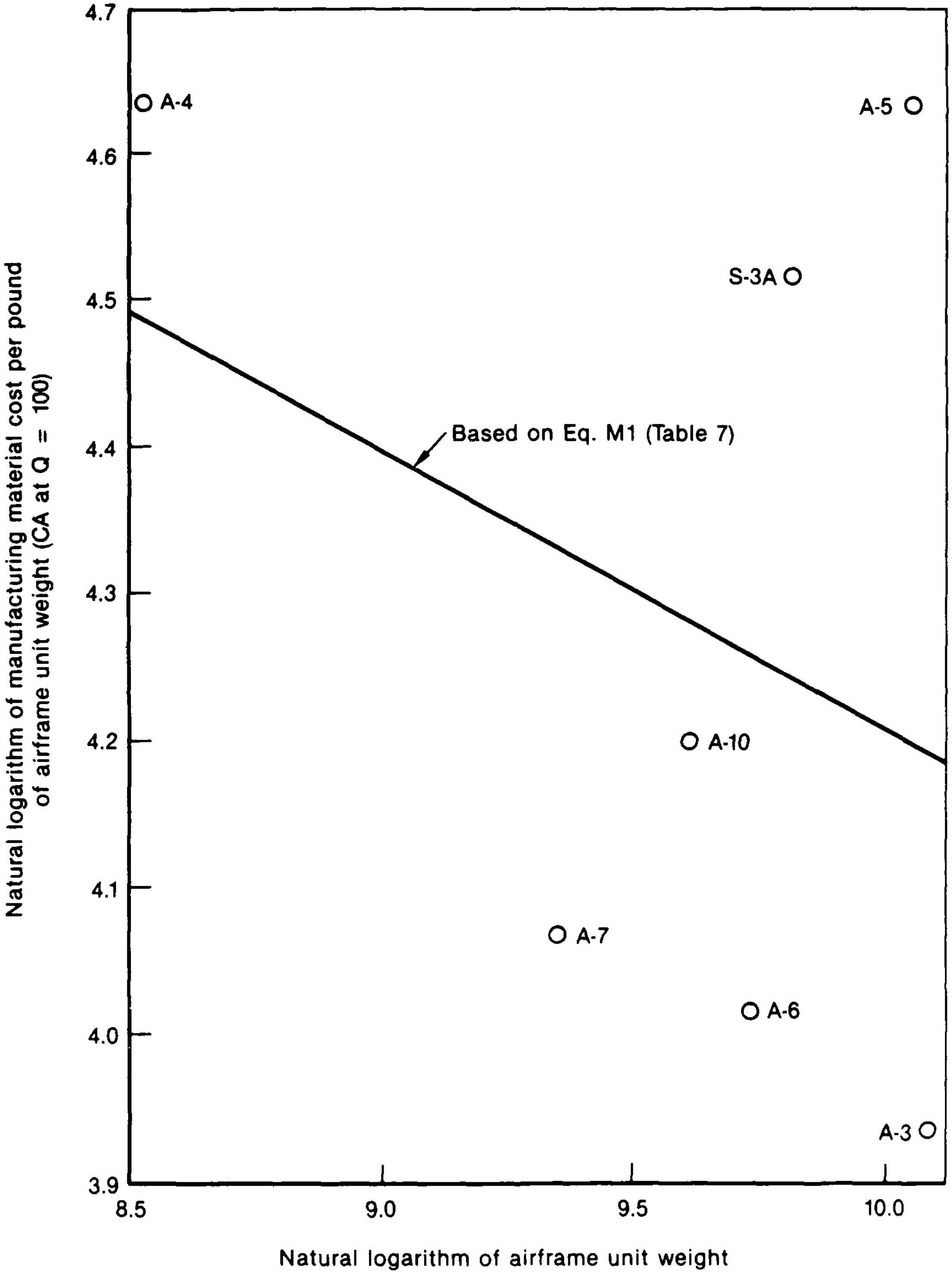

Fig. 6—Manufacturing material cost per pound as a function of airframe unit weight

Table 7

MANUFACTURING MATERIAL COST ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	SIZE									
M1	$MATL_{100} = 46.4\ \underset{(.009)}{AUW^{.812}}$	.70	.31	12	7	-33	-14	+19	22	IO: A-3, A-4, A-5
M2	$MATL_{100} = 11.4\ \underset{(.009)}{EW^{.921}}$	.71	.31	12	7	-36	-5	+19	20	IO: A-3, A-4, A-5
M3	$MATL_{100} = 42.7\ \underset{(.019)}{WTAREA^{1.02}}$	.61	.36	8	7	-11	-26	+21	19	EXP MAG: WTAREA IO: A-3, A-5
	SIZE/PERFORMANCE									
M4	$MATL_{100} = 194\ \underset{(.015)}{AUW^{.652}}\ \underset{(.049)}{SPCLS^{.543}}$	.86	.24	12	7	-17	-2	+30	16	LDIFF: SPCLS IO: A-4, A-5, S-3
M5	$MATL_{100} = 61.9\ \underset{(.013)}{EW^{.742}}\ \underset{(.048)}{SPCLS^{.537}}$	.87	.23	13	7	-20	+4	+30	18	LDIFF: SPCLS IO: A-3, A-5, S-3
M6	$MATL_{100} = 168\ \underset{(.019)}{WTAREA^{.829}}\ \underset{(.037)}{SPCLS^{.628}}$	.84	.25	11	7	+1	-9	+33	14	LDIFF: SPCLS IO: A-3, A-5, S-3
	SIZE/CONSTRUCTION, PROGRAM									
None										

VIII. DEVELOPMENT SUPPORT

Development support cost per pound is plotted as a function of airframe unit weight in Fig. 7. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 8. As indicated, we were not able to identify any estimating relationships which satisfied our initial screening criterion regarding variable significance.

Development support cost as a percentage of nonrecurring engineering cost was also examined and is summarized in Table 9.[1]

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[1]Nonrecurring engineering cost is a logical denominator since the mockups and test articles that make up development support are required for the airframe design effort.

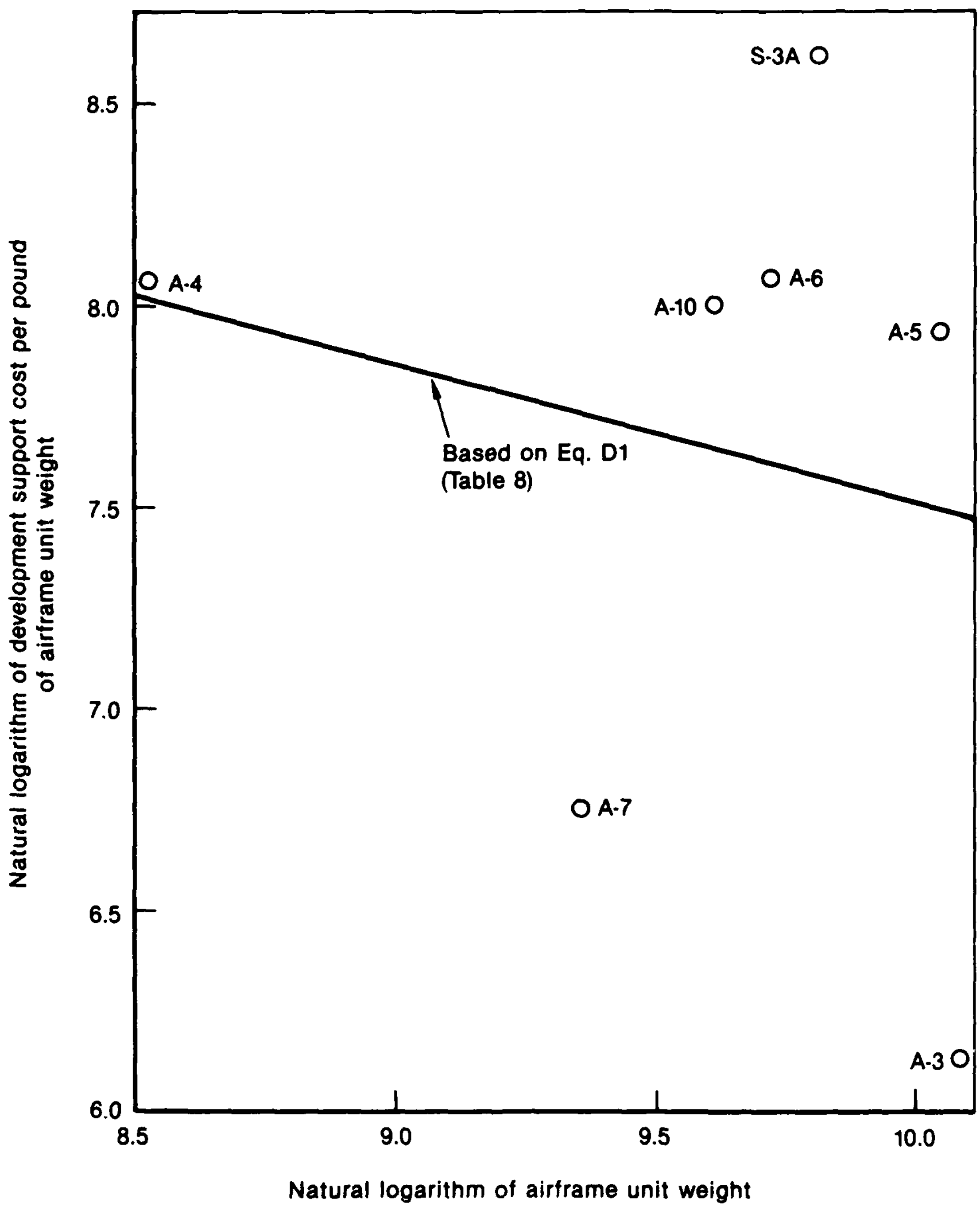

Fig. 7—Development support cost per pound as a function of airframe unit weight

Table 8

DEVELOPMENT SUPPORT COST ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics				Relative Deviations (%)				Comments
		R^2	SEE	F	N	A-6	A-10	S-3	Abs Avg	
	SIZE									
D1	DS $= 85.9\ AUW^{.660}$ (.201)	.14	.95	1	7	+2	-12	+45	20	VAR SIG: AUW EQ SIG: F-TEST IO: A-3, A-7, S-3
D2	DS $= 33.3\ EW^{.730}$ (.205)	.14	.95	1	7	0	-6	+45	17	VAR SIG: EW EQ SIG: F-TEST IQ: A-3, A-7, S-3
D3	DS $= 679\ WTAREA^{.559}$ (.303)	.06	.99	0	7	+11	-23	+46	27	VAR SIG: WTAREA EQ SIG: F-TEST IO: A-3, A-4, A-7, S-3
	SIZE/PERFORMANCE									
None										
	SIZE/CONSTRUCTION, PROGRAM									
None										

Table 9

DEVELOPMENT SUPPORT COST AS A PERCENTAGE OF UNIT 1 ENGINEERING COST

Aircraft	Unit 1 Engineering Hours	Unit 1 Engineering Cost ($M)(a)	Development Support Cost ($M)	Dev Support as a Percentage of Unit 1 Engr Cost
A-3	1,187,000	32.6	10.6	32
A-4	1,067,000	29.3	16.4	56
A-5	5,945,000	163.5	65.3	40
A-6	4,432,000	121.9	54.6	45
A-7	1,595,000	43.9	10.2	23
A-10	2,596,000	71.4	43.2	61
S-3	7,357,000	202.3	102.2	51
Average				44

(a)At $27.50 per hour.

IX. FLIGHT TEST

Flight test cost per aircraft is plotted as a function of the quantity of flight test aircraft in Fig. 8. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 10. General observations regarding these equations are as follows:

1. The variable TESTAC in Eq. F1 is not significant at the 5 percent level.
2. The magnitude of the variable TESTAC is greater than one in equations F1 through F4 and, in fact, is greater than two in equations F2 through F4.
3. None of the estimating relationships listed in Table 10 is recommended.

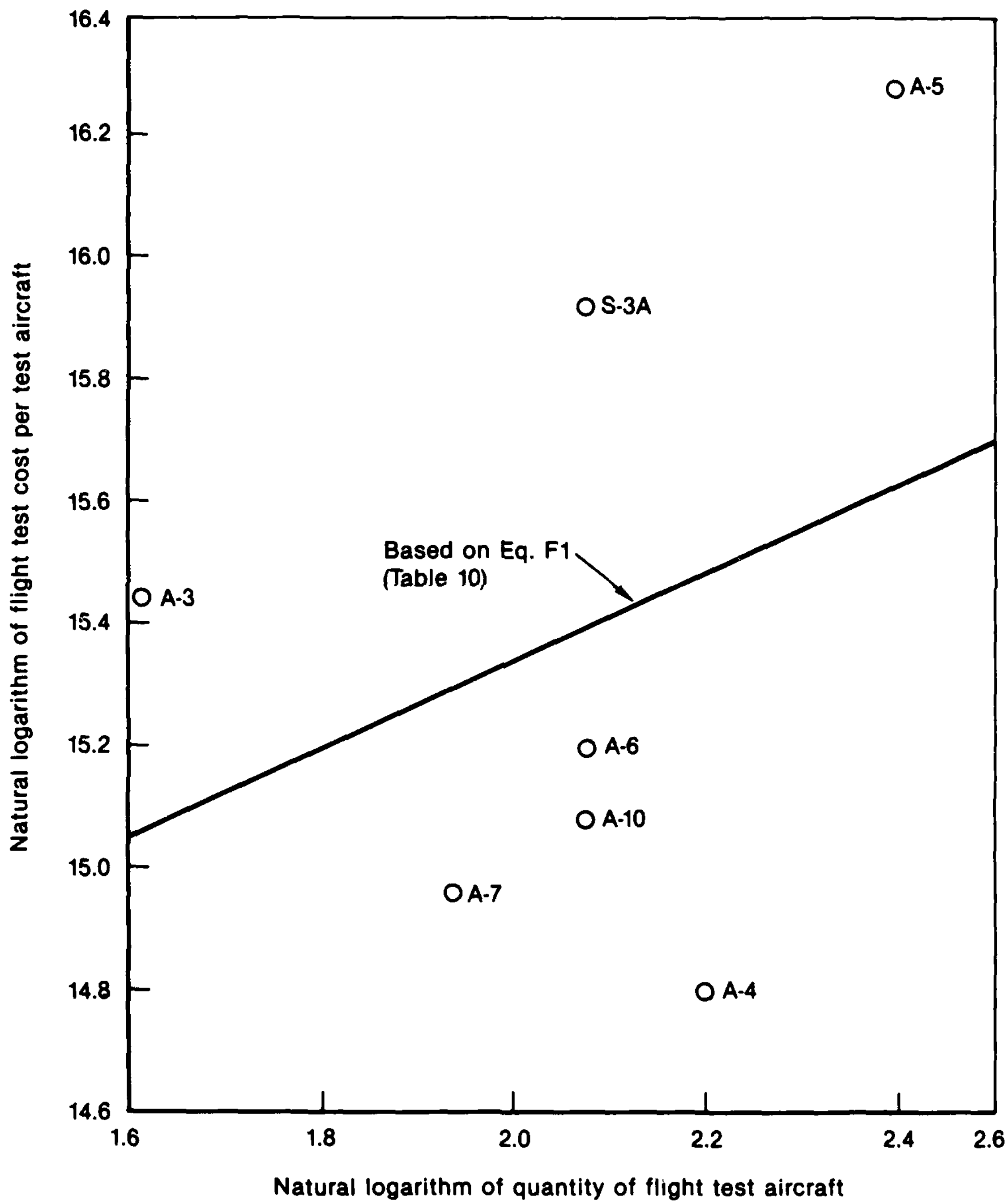

Fig. 8—Flight test cost per test aircraft as a function of the quantity of flight test aircraft

Table 10

FLIGHT TEST COST ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	TESTAC									
F1	$FT = 1260\ TESTAC^{1.73}$ (.064)	.40	.56	3	7	-41	-59	+30	43	VAR SIG: TESTAC EQ SIG: F-TEST IO: A-3, A-4, A-5
	SIZE/TESTAC									
F2	$FT = .128\ AUW^{.856}\ TESTAC^{2.15}$ (.012) (.008)	.86	.31	12	7	-45	-44	+23	37	EXP MAG: TESTAC IO: A-3, A-4, A-5
F3	$FT = .0193\ EW^{1.00}\ TESTAC^{2.20}$ (.007) (.005)	.89	.27	16	7	-48	-31	+23	34	EXP MAG: TESTAC IO: A-3, A-4, A-5
F4	$FT = .0167\ WTAREA^{1.24}\ TESTAC^{2.48}$ (.008) (.004)	.88	.28	15	7	-17	-60	+24	34	EXP MAG: TESTAC IO: A-5
	PERFORMANCE/TESTAC									
None										

X. QUALITY CONTROL

Quality control hours per pound are plotted as a function of airframe unit weight in Fig. 9. The data, which do not fit any obvious pattern, are available for only five aircraft. Consequently, regression analysis does not seem appropriate. However, since quality control is closely related to direct manufacturing labor, it can be estimated as a percentage of same. The ratio of cumulative quality control hours to cumulative manufacturing labor hours is as follows:

Aircraft	Ratio (at Q = 100)
A-5	.098
A-6	.076
A-7	.104
A-10	.140
S-3	.171
Average	.118

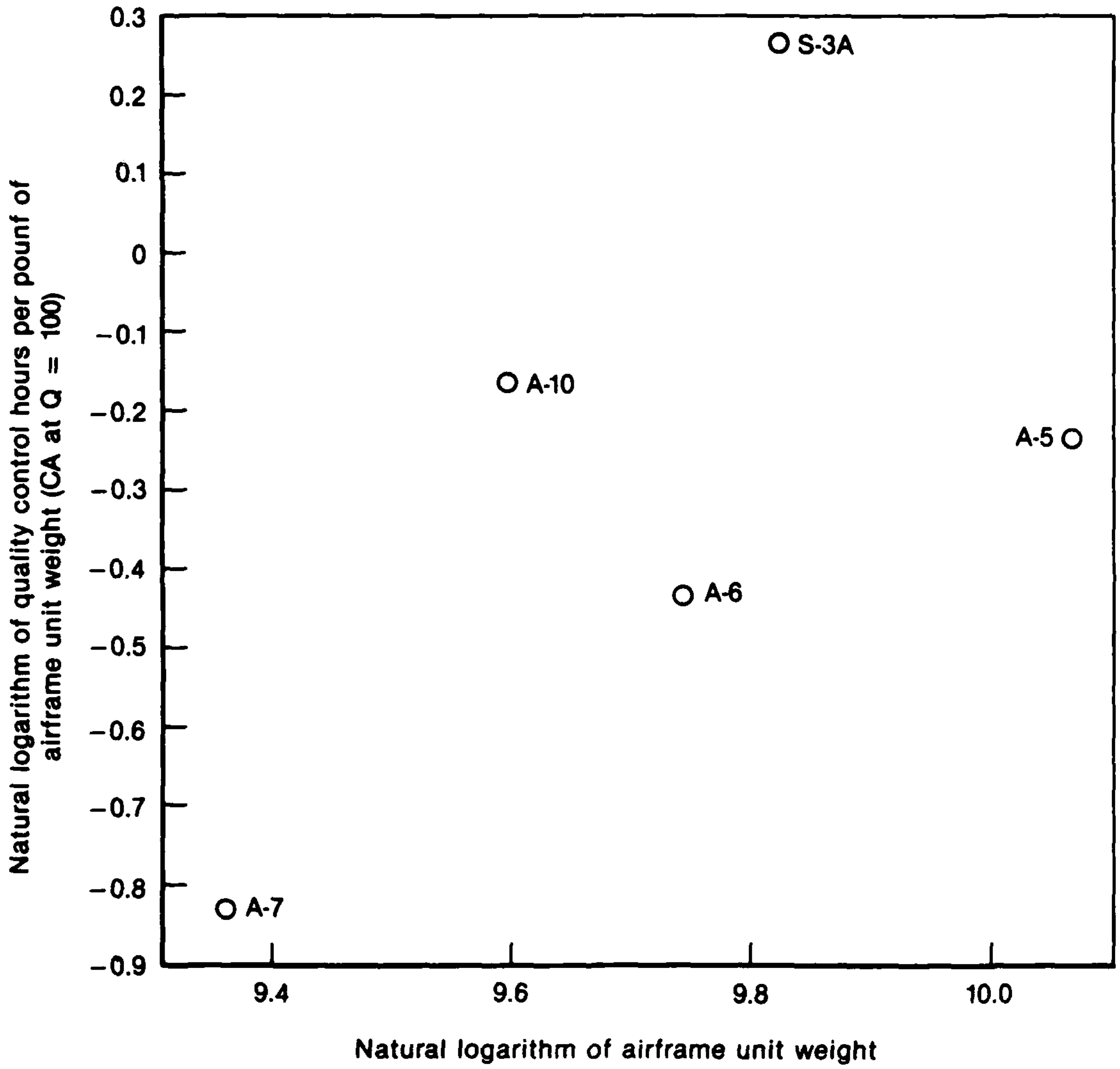

Fig. 9—Quality control hours per pound as a function of airframe unit weight

XI. TOTAL PROGRAM COST

Total program cost per pound is plotted as a function of airframe unit weight in Fig. 10. Estimating relationships in which all equation variables are significant at the 5 percent level are provided in Table 11. General observations regarding these equations are as follows:

- The exponents of the size variables in Eqs. P2 through P4 are all greater than one.
- None of the size/performance combinations examined satisfied our initial screening criterion with respect to variable significance.
- The exponent of the variable AUW in Eq. P1 is determined largely by a single aircraft--the A-4 (that is, deletion of the A-4 would result in an equation with an exponent considerably greater than one (1.70 to be exact)).
- None of the estimating relationships listed in Table 11 is recommended.

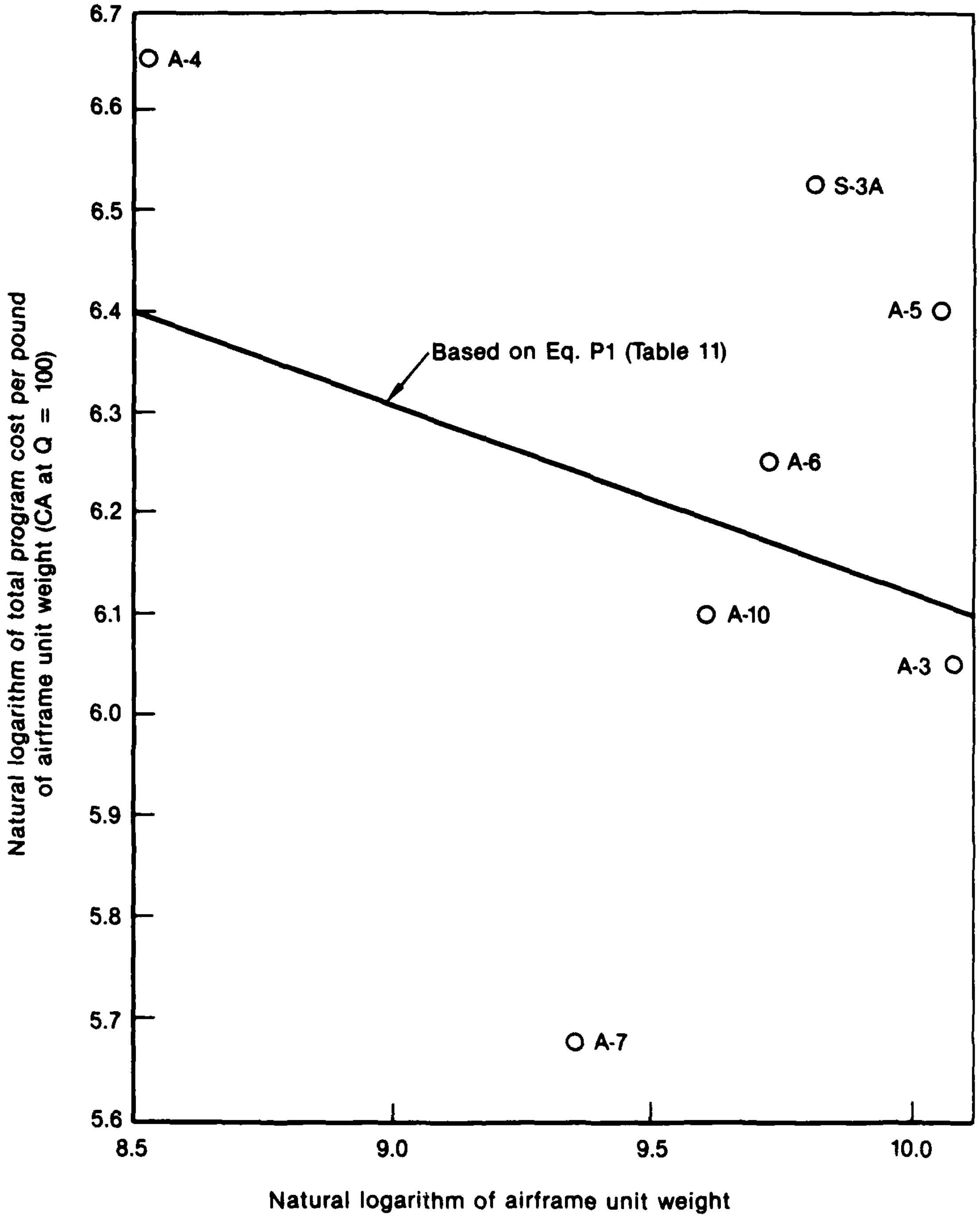

Fig. 10—Total program cost per pound as a function of airframe unit weight

Table 11

TOTAL PROGRAM COST ESTIMATING RELATIONSHIPS

Eq. No.	Equation	Statistics R^2	SEE	F	N	Relative Deviations (%) A-6	A-10	S-3	Abs Avg	Comments
	SIZE									
P1	$PROG_{100} = 225\ AUW^{.852}$ (.012)	.67	.35	10	7	-2	-22	+22	15	IO: A-4, A-7
P2	$PROG_{100} = 29.4\ EW^{1.02}$ (.005)	.76	.30	16	7	-4	-10	+22	12	EXP MAG: EW IO: A-3, A-4, A-5, A-7, S-3
P3	$PROG_{100} = 144\ WTAREA^{1.12}$ (.015)	.64	.37	9	7	+16	-35	+24	25	EXP MAG: WTAREA IO: A-3, A-4, A-5, A-7, S-3
	SIZE/PERFORMANCE									
None										
	SIZE/CONSTRUCTION, PROGRAM									
P4	$PROG_{100} = 910\ WTAREA^{1.02}\ AVAUW^{.467}$ (.008) (.027)	.87	.24	14	7	-7	+13	-6	9	EXP MAG: WTAREA IO: A-3, A-4, A-7, A-10

XII. CONCLUSIONS

We were not able to identify any acceptable estimating relationships for any of the individual cost elements or for total program cost. We suggest that users develop estimates for proposed attack aircraft either on the basis of analogy (using the data provided in this Note) or by using the equation set developed for all mission types.

We feel that our inability to develop a set of statistically-derived cost-estimating relationships for attack aircraft is the result of a sample which is *both* small and not as homogeneous as it appears at first glance. For example:

- The A-4 is less than half as big as the next smallest aircraft in the sample.
- The A-5 is a Mach 2 aircraft whereas all other sample aircraft are subsonic.
- The S-3 places considerably more emphasis on electronics than any of the other sample aircraft.
- The A-10 had the acquisition concepts of competitive prototyping and design-to-cost.
- The A-7, although classified as a new design, evolved from the F-8.

Consequently, given this amount of diversity in so small a sample, it would have been surprising if we had been able to develop a credible set of CERs.

COST-QUANTITY SLOPES

Minimum, maximum, and average cost-quantity slopes for the attack aircraft subsample are provided in Table 12.

Table 12

CUMULATIVE TOTAL COST-QUANTITY SLOPES

	Engineering	Tooling	Mfg. Labor	Mfg. Material	Quality Control	Total Program
Number of observations	7	7	7	7	5	7
Range (%)	106-116	112-138	140-162	158-194	150-160	128-142
Average (%)	110	122	154	180	154	134
Exponent	.138	.286	.623	.848	.623	.422

NOTES: Results are based on first 200 units; cumulative average slope = cumulative total slope divided by two.

FULLY BURDENED LABOR RATES

All cost elements estimated directly in dollars are in 1977 dollars. Suggested 1977 fully burdened hourly labor rates (and those used to estimate total program cost) are:

Engineering	27.50
Tooling	25.50
Manufacturing labor	23.50
Quality control	24.00

For estimates in 1986 dollars, the following hourly labor rates and adjustment factors are suggested:

Engineering	59.10
Tooling	60.70
Manufacturing labor	50.10
Quality control	55.40
Manufacturing material (index)	1.94
Development support (index)	1.94
Flight test (index)	1.94
Total program (index)	2.13

The 1986 labor rates are based on data provided by seven contractors:

Labor Category	Hourly Rates ($) Average	Range	Range About Average (%)
Engineering	59.10	47.70-70.00	-19, +18
Tooling	60.70	56.50-65.00	- 7, + 7
Manufacturing labor	50.10	41.70-58.00	-17, +16
Quality control	55.40	49.10-62.60	-11, +13

Note that with the exception of tooling, the range about the average rate is at least + or -10 percent. Such differences could arise from differences in accounting practices, business bases, and capital investment. Irrespective of cause, however, labor rate variation is one more component of a larger uncertainty which already includes the error associated with statistically-derived estimating relationships and questions about the proper cost-quantity slope. Furthermore, in addition to the inter-contractor differences, these rates are also subject to temporal change--accounting procedures, relative capital/labor ratio, etc. Thus, the 1986 fully burdened rate is qualitatively different than the 1977 rate. Unfortunately, trying to estimate the magnitude of such quality changes, even very crudely, is a study in itself and beyond the scope of this analysis.

The material, development support, and flight test escalation indexes are based on data provided in AFR 173-13.[1] For the years 1977-1984, the airframe index presented in Table 5-3 ("Historical Aircraft Component Inflation Indices") was used. For the years 1985 and 1986, the aircraft and missile procurement index presented in Table 5-2 ("USAF Weighted Inflation Indices Based on OSD Raw Inflation and Outlay Rates") was used. The total program cost adjustment factor was then determined on the basis of a weighted average (at Q = 100) of the individual cost elements.

[1]See Ref. 6.

Appendix

CORRELATION MATRIXES

This appendix contains correlation matrixes for the full attack aircraft estimating sample. Table A.1 provides Pearson correlation coefficients for all possible pairwise combinations of dependent and independent variables. Table A.2 provides coefficients for all possible pairwise combinations of independent variables.

Table A.1

CORRELATION MATRIX: COST VARIABLES WITH POTENTIAL EXPLANATORY VARIABLES

EXPLANATORY VARIABLES	COST VARIABLES						
	ln ENGR	ln TOOL	ln LABR	ln MATL	ln DEVSPT	ln FLTTST	ln PROG
SIZE							
ln AUW	0.65	0.43	0.87	0.84	0.38	0.52	0.82
ln EW	0.64	0.57	0.94	0.84	0.37	0.53	0.87
ln WTAREA	0.51	0.55	0.89	0.78	0.24	0.41	0.80
PERFORMANCE							
ln SPEED	0.11	0.33	0.25	0.42	0.03	0.60	0.26
ln SPCLS	0.42	0.40	0.39	0.69	0.35	0.83	0.49
ln CLIMB	0.22	0.17	0.12	0.36	0.21	0.62	0.20
ln USELD	-0.54	-0.71	-0.76	-0.92	-0.35	-0.80	-0.82
CONSTRUCTION							
ln ULTLD	-0.22	-0.21	-0.39	-0.24	-0.13	0.12	-0.35
ln CARRDV	-0.08	0.36	0.14	0.07	-0.16	0.18	0.11
ln ENGLOC	0.24	0.24	0.39	0.29	0.15	-0.05	0.38
ln WGTYPE	-0.08	0.36	0.14	0.07	-0.16	0.18	0.11
ln WGWET	0.43	0.05	0.01	0.13	0.52	0.43	0.16
ln EWAUW	-0.36	0.44	-0.11	-0.40	-0.19	-0.22	-0.15
ln AVAUW	0.60	0.54	0.48	0.43	0.58	0.50	0.60
ln BLBOX	0.68	-0.26	0.14	0.36	0.62	0.32	0.31
PROGRAM							
ln TESTAC	0.42	0.00	-0.17	0.24	0.60	0.63	0.10
ln TOOLCP	-0.85	-0.60	-0.90	-0.90	-0.66	-0.69	-0.95
ln ENGDV	0.63	0.15	0.29	0.21	0.64	0.51	0.41
ln EXPDV	0.79	0.56	0.89	0.77	0.64	0.51	0.90
ln PRGDV	-0.54	0.12	-0.12	-0.41	-0.46	-0.53	-0.27

Table A.2

CORRELATION MATRIX FOR IDENTIFICATION OF PAIRWISE COLLINEARITY

	SIZE			TECHNICAL/PERFORMANCE				CONSTRUCTION									PROGRAM				
	ln AUW	ln EW	ln WTAREA	ln SPEED	ln SPCLS	ln CLIMB	ln USELD	ln ULTLD	ln CARRDV	ln ENGLOC	ln WGTYPE	ln WGWET		ln EWAUW	ln AVAUW	ln BLBOX	ln TESTAC	ln TOOLCP	ln ENGDV	ln EXPDV	ln PRGDV
SIZE																					
ln AUW	1.00																				
ln EW	0.99	1.00																			
ln WTAREA	0.94	0.95	1.00																		
TECHNICAL/PERFORMANCE																					
ln SPEED	0.21	0.24	0.10	1.00																	
ln SPCLS	0.38	0.38	0.30	0.89	1.00																
ln CLIMB	0.11	0.11	-0.06	0.94	0.88	1.00															
ln USELD	-0.74	-0.77	-0.77	-0.53	-0.72	-0.36	1.00														
CONSTRUCTION																					
ln ULTLD	-0.40	-0.40	-0.60	0.69	0.41	0.78	0.22	1.00													
ln CARRDV	-0.01	0.08	-0.10	0.49	0.17	0.35	-0.20	0.50	1.00												
ln ENGLOC	0.41	0.41	0.61	-0.64	-0.35	-0.75	-0.29	-0.99	-0.47	1.00											
ln WGTYPE	0.00	0.08	-0.10	0.49	0.17	0.35	-0.20	0.50	1.00	-0.47	1.00										
ln WGWET	-0.07	-0.05	-0.36	0.41	0.31	0.60	0.08	0.68	0.49	-0.69	0.49	1.00									
ln EWAUW	-0.57	-0.43	-0.44	-0.02	-0.21	-0.06	0.23	-0.81	0.41	-0.20	0.41	0.15		1.00							
ln AVAUW	0.29	0.36	0.15	0.13	0.11	0.14	-0.30	0.08	0.64	-0.06	0.64	0.67		0.28	1.00						
ln BLBOX	0.42	0.33	0.18	-0.21	-0.07	-0.07	-0.05	-0.12	0.02	0.12	0.02	0.44		-0.58	0.49	1.00					
PROGRAM																					
ln TESTAC	-0.82	-0.24	-0.37	0.47	0.62	0.69	-0.10	0.55	-0.04	-0.51	-0.04	0.64		0.03	0.18	0.12	1.00				
ln TOOLCP	-0.90	-0.92	-0.82	-0.17	-0.38	-0.12	0.75	0.36	-0.15	-0.38	-0.15	-0.20		0.34	-0.63	-0.54	0.01	1.00			
ln ENGDV	0.24	0.26	0.06	-0.30	-0.26	-0.17	0.07	-0.12	0.26	0.09	0.26	0.60		0.05	0.83	0.75	0.07	-0.54	1.00		
ln EXPDV	0.84	0.86	0.88	-0.03	0.26	-0.03	-0.59	-0.56	-0.26	0.55	-0.26	-0.02		-0.30	0.36	0.34	-0.05	-0.88	0.40	1.00	
ln PRGDV	-0.34	-0.29	-0.04	-0.39	-0.35	-0.39	0.21	-0.44	-0.47	0.42	-0.47	-0.74		0.42	-0.58	-0.78	-0.36	0.46	-0.55	-0.09	1.00

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